

Study on The Wear-Resistance of Crust Breaker for Aluminium Electrolysis

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Abstract

In order to improve wear resistance of crust breaker head in aluminium reduction cells, plasma surfacing was used to prepare composite wear resistant coating on Q235 steel. Scanning electron microscope, UMT-3 friction wear testing machine and others were used to study the interface morphology and wear resistance of the surface coating. The results show that the surface coating forms a solid metallurgical bond with the carbon steel matrix, and the carbide strengthening phase is distributed uniformly in the coating material as island shapes, which effectively plays the role of skeleton and support. The scratches on the surface of the surface coating are smooth, the thickness is 150 μm , and the mass loss is only 0.06 mg. The wear resistance of the surfacing coating is more than 40 times that of the ordinary breaker material. The wear-resistant coating prepared by plasma surfacing can obviously improve the wear-resistant performance of the crust breaker head and greatly increase its service life, which is of great significance for reducing the production cost for smelters.

Keywords: Aluminium reduction cell, Crust breaker, Q235 steel, Plasma surfacing, Coating, Wear resistance.

1. Introduction

As an important part of the automatic feeding system for aluminium electrolysis cells, the crust breaker needs to periodically open the electrolyte crust surface to add raw materials. Due to prolonged frictional wear and abrasion from the hard crust, as well as abrasion from the electrolyte, raw material and high-temperature corrosion by the molten electrolyte salt, the breaker material continuously deteriorates. Eventually, this leads to a reduction in size at the end of the breaker, resulting in a "pencil tip" shape and failure [1-2], as shown in Figure 1. The commonly used materials for these breakers in aluminium smelters are Q235 steel or 45# steel, which have poor wear resistance with a typical lifespan of 3-6 months. Frequent replacement and maintenance of these crust breakers not only increase labour intensity for electrolysis operators but also raise production costs for companies. Additionally, the lost breaker material enters into the aluminium melt, leading to excessive Fe impurity content and causing a decline in original aluminium quality [3-4].

Plasma Transferred Arc (PTA) welding is an advanced technique that utilizes a high-temperature plasma as the heat source to simultaneously melt alloy powder and the near-surface layer of the work piece (Figure 2). This process involves the rapid heating, melting, mixing, diffusion, and solidification of the alloy powder and base material surface as the plasma arc moves. Upon departure of the plasma beam, self-quenching occurs, resulting in the formation of a high-performance alloy layer on the work piece surface. The key features of PTA welding technology are as follows: (1) produces various types of functional coatings; (2) forms metallurgical bonds

with the substrate, ensuring strong adhesion; (3) achieves a uniform coating-substrate structure; (4) has low dilution rate for coated layers; and (5) it is easy to mechanize and automate [5-6].

This paper applies PTA welding technology to the crust breaker used in aluminium electrolysis cells to deposit a wear-resistant coating on its surface. The goal is to enhance the wear resistance of the crust breaker, thereby extending its service life, reducing impurity content in molten aluminium, improving primary aluminium quality, relieving labour intensity of workers, and lowering overall production costs.



Figure 1. Crust breaker in aluminium reduction cell.

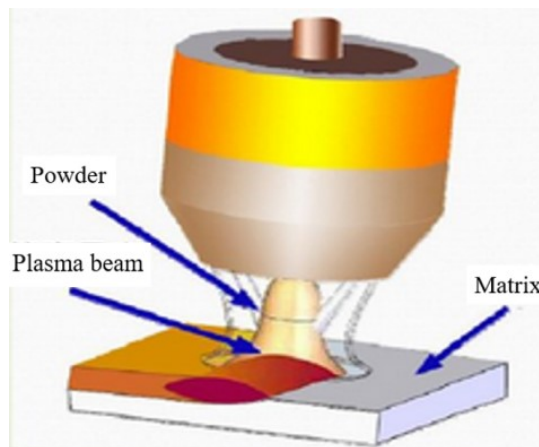


Figure 2. Schematic diagram of the PTA welding.

2. Experimental

2.1 Matrix Material

Q235 steel with excellent weld ability and low price is selected as the best matrix material. The composition of Q235 steel is shown in Table 1.

Table 1. Composition of Q235 steel.

Composition	C	Mn	Si	S	P	Fe
Content	≤ 0.22 %	≤ 1.4 %	≤ 0.35 %	≤ 0.05 %	≤ 0.045 %	remain

2.2 Coating Materials

The coating materials are a self-produced composite wear-resistant powder, consisting of alloy powder and carbide-reinforced powder. Figure 3 (a) illustrates the morphology of the alloy powder, which exhibits a spherical shape with particle sizes ranging from 50-150 μm . Meanwhile, Figure 3 (b) shows the morphology of the composite powder after incorporating the carbide-reinforced phase, with uniformly distributed plate particles within the spherical alloy powder.

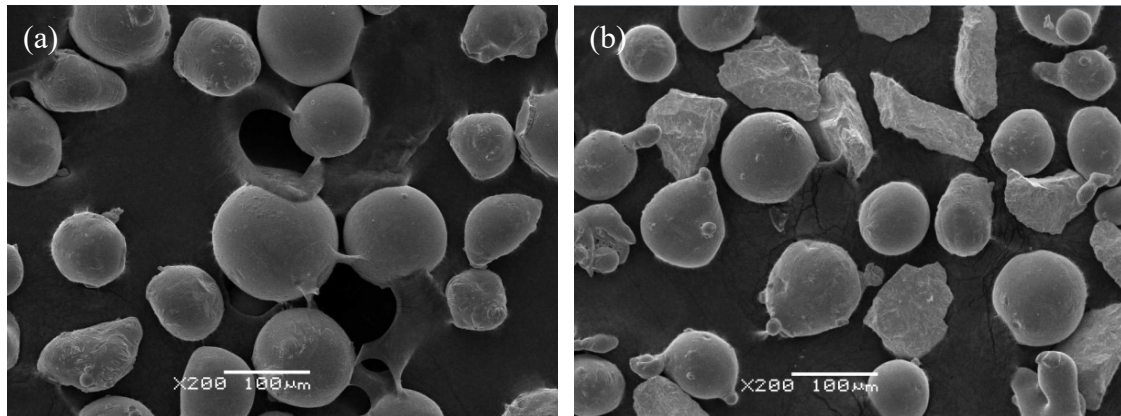


Figure 3. Left: Morphology of alloy powder (a), Right: Composite powder (b).

2.3 PTA Welding Process

The process parameters for PTA welding are: ion gas flow rate of 5.6 to 6.0 L/min, protective gas flow rate of 12 to 13 L/min, powder feed gas flow rate of 4.2 to 4.5 L/min, powder feed rate ranging from 40 to 65 g/min, welding speed set at 500 to 700 mm/min, and cladding current maintained between 180 and 195 A.

2.4 Analysis Methods

The coated materials were cut into 20 mm \times 15 mm \times 4 mm cubic samples using wire cutting. Then, their surfaces were cleaned with acetone to remove any oil residues, and polished on 80#, 220#, 500#, 1000#, and 2000# sandpaper to ensure a smooth finish. Each sample was washed with alcohol, dried, and weighed on a high-precision weighing scale (accuracy of 10-5 g) before the wear test, recording the initial weight. The wear test was carried out using the friction and wear test CETR-UMT-3 equipment shown in Figure 4 (a). The specific parameters are detailed in Table 2, and a schematic diagram illustrating the process is presented in Figure 4 (b). During the test, a friction ball repeatedly moved along the surface of each sample in its direction of motion. At the end of the test, each sample was immediately weighed again. The difference between final and initial weights represented the wear resistance properties.

Table 2. Parameters of friction and wear test machine.

Type	Load	Reciprocating displacement	Speed	Time	Ball type	Ball diameter	Ball hardness
Information	40 N	5 mm	50 m/s	30 min	GCr15	6 mm	55 HRC

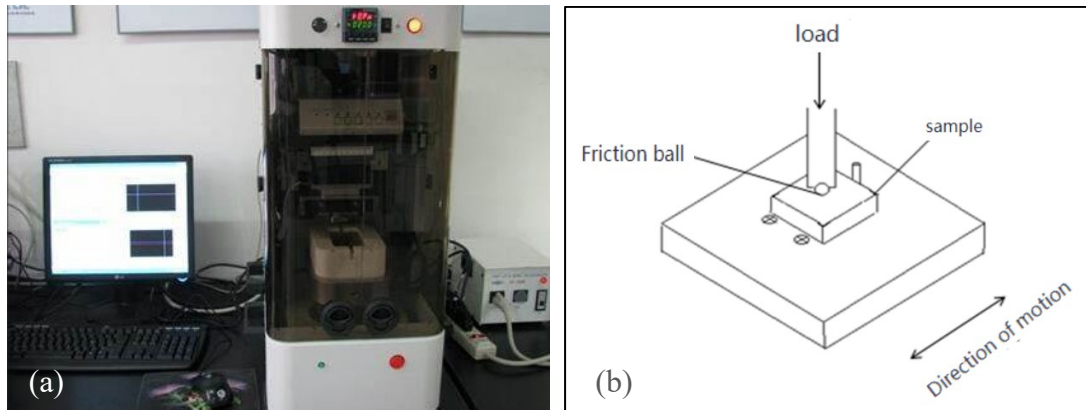


Figure 4. CETR-UMT-3 friction and wear test equipment (a) and wear test diagram (b).

3. Results and Discussion

3.1 Interface Morphology of the Welding Coating

Figure 5 illustrates the morphology of the fusion zone between the Q235 steel and the welding coating. In Figure 5 (a), the darker-coloured area on the left represents the Q235 matrix material, while the lighter-coloured area on the right corresponds to the welding coating. It is evident from Figure 5 (a) that during PTA welding, the coating is melted at high temperature on the substrate surface to form a molten pool. The liquid alloy within this pool melts, mixes, diffuses, and solidifies with the substrate, establishing a robust metallurgical bond between them. Figure 5 (b) displays a morphological distribution of carbide reinforcing phases within the welding coating. Darker areas represent alloy material, while bright white blocks indicate carbide reinforcing phase material. This reveals that added carbide reinforcing phases are uniformly distributed in an island-like pattern within the alloy layer material. The strengthening phase exhibits good compatibility with welding layer performance. In addition, no evidence of cracking or porosity at fusion lines was observed, indicating its effective role in providing structural reinforcement for coatings.

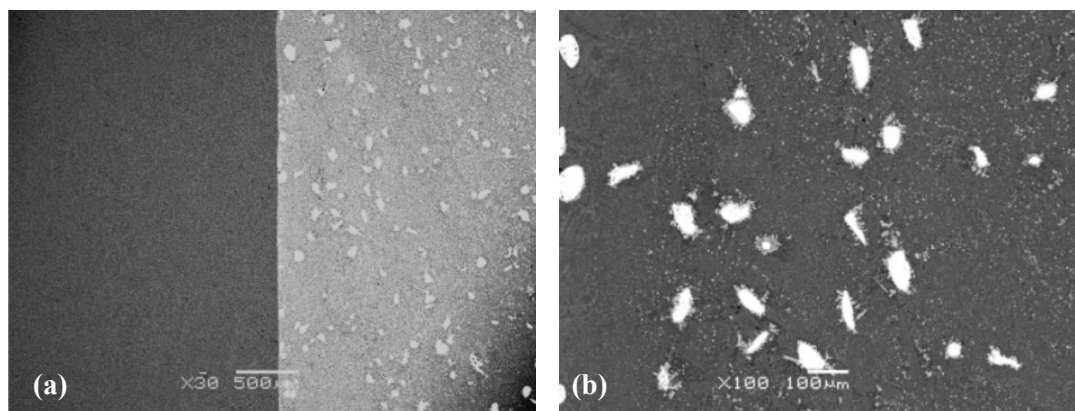


Figure 5. The fusion surface (a) and the reinforcing phase (b).

3.2 Macroscopic Morphological Analysis of Worn Samples

Figure 6 presents macroscopic images of the worn morphology resulting from the linear reciprocating wear test on the crust breaker of Q235 steel and PTA welding coating. The images clearly illustrate that the surface hardness of Q235 steel is low, leading to poor wear resistance. Under 30 minutes at 40 N pressure wear condition, the material's surface exhibits significant wear

with wide and deep scratch pits. In contrast, the PTA welding coating demonstrates high hardness and superior wear resistance. Under identical wear conditions, its surface displays narrower and shallower scratch pits. The PTA welding coating has exhibited a noticeable wearing resistance.

After weighing the samples, the mass loss of the PTA welding coating and the Q235 steel crust breaker was 0.06 mg crust breaker and 2.54 mg respectively. Therefore, the linear wear resistance of the PTA welding coating is approximately 40 times greater than Q235 steel.

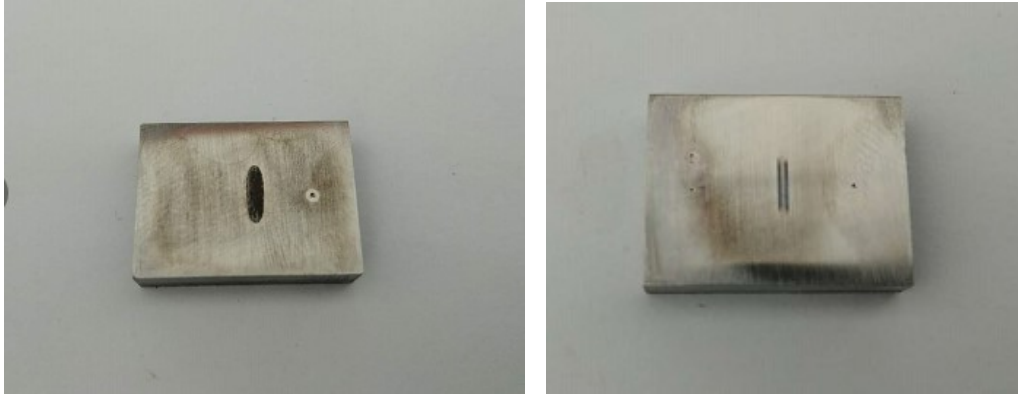


Figure 6. Scratch pit of Q235 steel (a) and Q235 steel PTA welding coating (b).

3.3 Microscopic Morphological Analysis of Worn Samples

Figure 7 presents microscopic images of the worn morphology resulting from the linear reciprocating wear test on the crust breaker of Q235 steel and PTA welding coating.

As observed in Figure 7 (a) and (b), the thickness of the wear track on the Q235 steel is 1400 μm , whereas that of the PTA welding coating is 150 μm , highlighting a difference of nearly tenfold.

Figure 7 (c) presents an image magnification of the microscopic morphology of scratch pits on the surface of the Q235 steel. The image reveals that the surface scratch pits exhibit concave and pear-shaped grooves, indicating predominant adhesive wear with some abrasive wear. During the wear process, the frictional force F is primarily composed of F_X and F_Y , where F_X induces micro-frictional wear on the sample surface, while F_Y causes abrasive particle-induced wear by pressing into the sample. Due to its ferrite-pearlite structure with a hardness of 120 HB, the Q235 steel has low hardness and poor strength, making it prone to plastic deformation and detachment. The detached particles adhere to both the counter-rotating ball and sample surfaces. Over prolonged friction time, these particles gradually form pear-shaped wear tracks characterized by groove patterns indicative of adhesive wear behaviour. Consequently, the Q235 steel exhibits poor wear resistance [7].

Figure 7 (d) presents an image magnification of the micro structural morphology of scratch pits on the PTA welding coating. The image reveals that the scratch pits on the surface of the PTA welding coating sample exhibits a relatively smooth and flat profile. This can be attributed to the high hardness (500 HV) of the martensitic structure in the coating material, which imparts significant strength and exceptional wear resistance. Furthermore, the uniformly embedded carbide reinforcing phase (1800 HV) within the alloy coating effectively impedes micro cutting motion induced by repeated linear frictional wear conditions, thereby minimizing effective wear on the alloy layer [8-9].

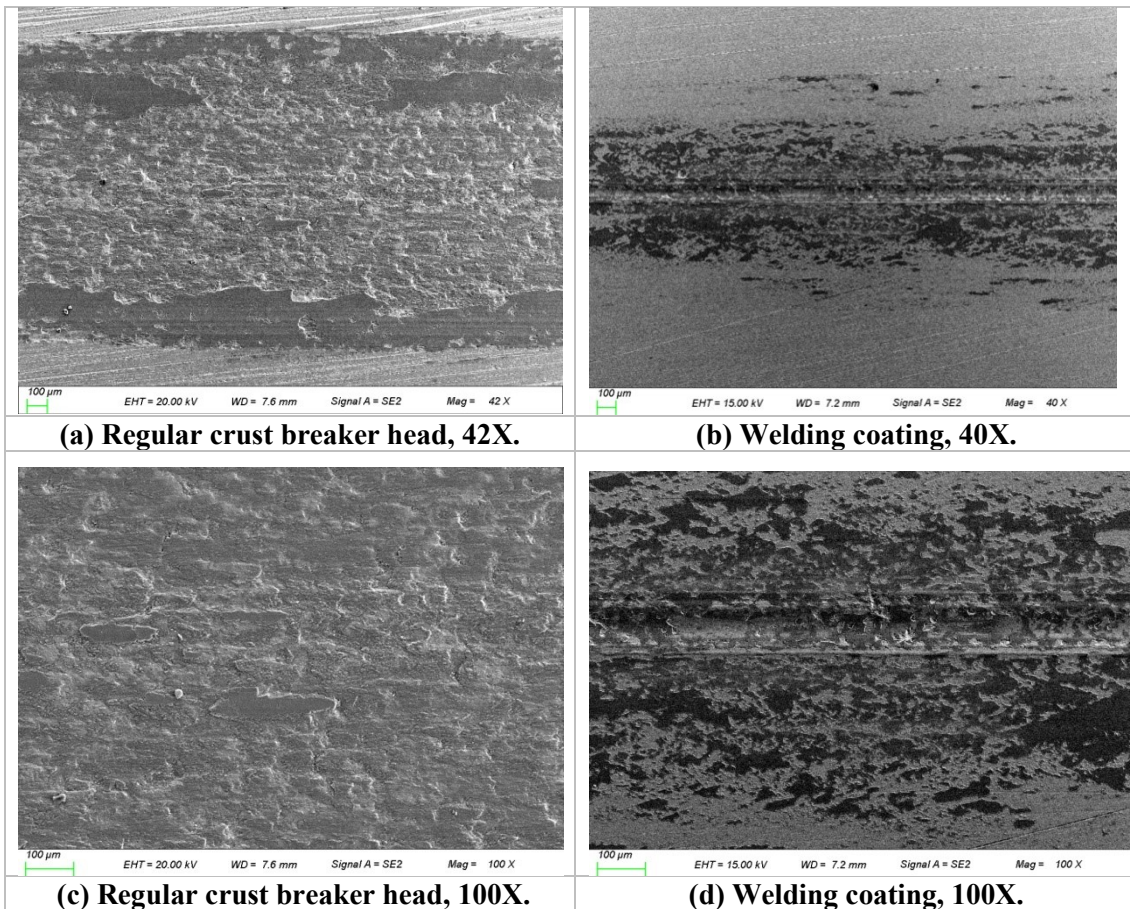
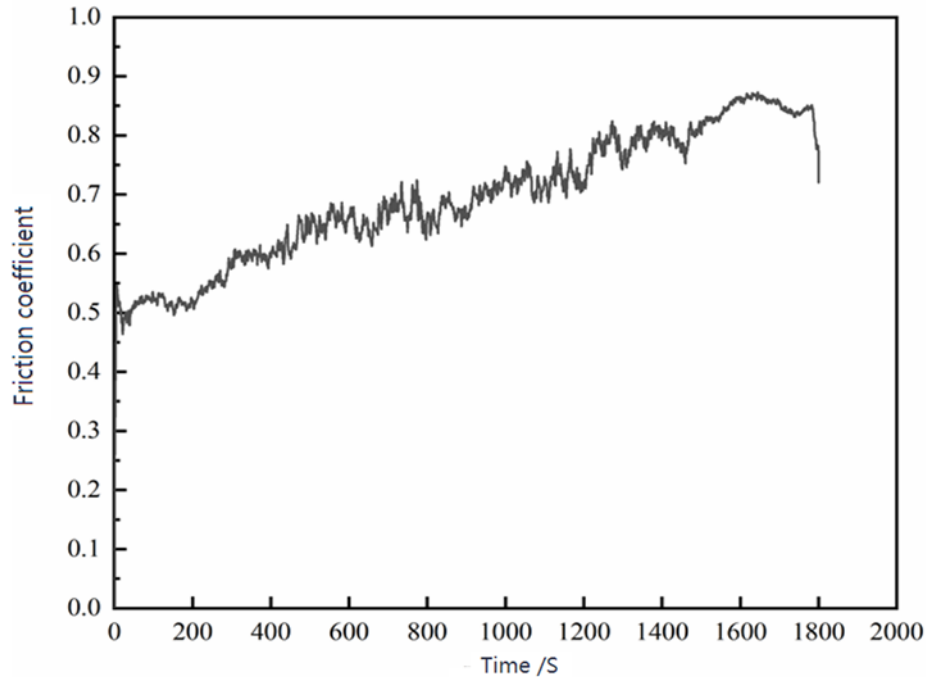


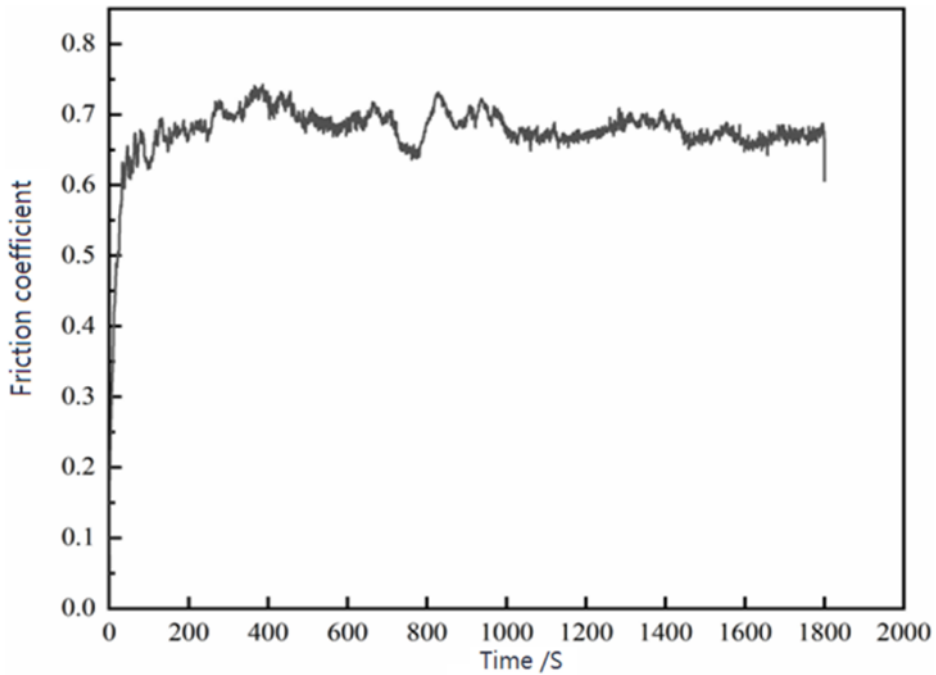
Figure 7. Microscopic morphology of scratch pits on the surface of crust breaker of Q235 steel and PTA welding coating.

3.4 Dynamic Friction Coefficient

Figures 8 (a) and (b) depict the dynamic friction coefficient curves for the Q235 steel and PTA welding coating. The curve for the Q235 steel indicates that due to its lower base hardness, there is initial plastic deformation at the contact surface upon application of a load of 40 N, resulting in relatively smooth contact surfaces and a small friction coefficient. As linear reciprocating friction time increases, adhesive wear occurs on the contact surface, gradually forming groove-shaped depressions and leading to increased abrasive wear. This results in an increase in surface roughness and a corresponding rise in dynamic friction coefficient. In contrast, the PTA welding coating exhibits minimal deformation at the contact surface under initial load pressure due to its higher inherent hardness. Additionally, carbide reinforcement within the coating further enhances its protective and supportive properties, strengthening both hardness and wear resistance. Consequently, as linear reciprocating friction time increases, there is no significant change in contact surface roughness; thus, a stable trend is observed in the dynamic friction coefficient, indicating superior wear resistance [10-11].



(a) Q235 steel.



(b) PTA welding coating.

Figure 8. Friction curves of Q235 steel (a) and PTA welding coating (b).

3.5 Industrial Applications

The wear-resisting crust breaker was implemented in an electrolytic aluminium smelter, and it underwent on-rack testing to assess its performance. The wear characteristics of the breaker were measured and statistically analysed after 3 and 6 months (Table 3). Comparative analysis revealed that the Q235 steel crust breaker exhibited poor wear resistance, requiring replacement after 6 months with an average wear weight of 8.25 kg. In contrast, the PTA welding crust breaker did not require replacement during this period and showed an average wear weight of only 0.47 kg.

The service life of the wear-resistant breaker has exceeded 44 months up to now. As shown in Figure 9, the full dimensions are well maintained, and the grooves in the PTA welding coating are still clearly visible, exhibiting excellent wear resistance. On the other hand, the Q235 steel breaker was substantially reduced after 6 months and could not be used in a normal way.

Table 3. Use of crust breaker.

Type	Mass loss, kg	
	3 months	6 months
Q235 breaker	4.54	8.25
Wear-resistant breaker	0.32	0.47



(a) Q235 steel breaker after 6 months.

(b) PTA welding breaker after 17 months.

(c) PTA welding breaker after 44 months.

Figure 9. Comparison of Q235 steel and PTA welding crust breaker.

Therefore, the use of PTA welding to apply a wear-resistant coating on the surface of the breaker significantly enhances its durability and extends its service life by up to five to ten times compared to conventional methods. This reduces the frequency for replacing breaker and can potentially save approximately 1.2 MRMB (165 kUSD) per year in comprehensive replacement costs for a 500 000 t/y aluminium smelter.

4. Conclusions

From this paper, the following can be concluded:

- The PTA welding coating formed a strong metallurgical bond with the carbon steel matrix, and the carbide strengthening phases were uniformly distributed in the coating as island shapes, which effectively play a skeleton and support role.
- From the friction and wear test results, it is evident that the scratch pit on the surface of the PTA welding coating is smooth and narrow, registering a thickness of 150 μm with only 0.06 mg mass loss, demonstrating a wear resistance 40 times greater than Q235 steel breaker.
- The use of PTA welding method to produce a wear-resistant coating on the surface of breaker can significantly enhance its wear resistance and greatly extend its service life, thereby playing a considerable role in reducing aluminium production costs.

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